Case Report

Effects of resistance-guided high intensity interval functional electrical stimulation cycling on an individual with paraplegia: A case report

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Background and Purpose: Individuals with spinal cord injury (SCI) are more than twice as likely to develop and die from cardio-metabolic diseases as compared to able-bodied. This increased risk is thought to be in part due to accelerated muscle atrophy and reduced blood flow through sublesional arteries. Thus, strategies to recondition paralyzed skeletal muscles may help reduce cardio-metabolic disease risk. The purpose of this case report was to examine the impact of a novel, resistance-guided, high intensity interval training functional electrical stimulation (RG-HIIT-FES) cycling program on cardio-metabolic health in people with chronic SCI.
Case Description: One adult female with chronic T10 SCI.
Intervention: A novel RG-HIIT-FES cycling program three times per week for 10 weeks. Measures of body composition and cardio-metabolic health (vascular endothelial function of the brachial artery via flow-mediated dilation) and HbA1c blood values were performed at baseline and following completion of the RG-HIIT-FES program.
Outcomes: Total body lean mass and legs lean mass increased 2.8% and 5.3% respectively while vastus lateralis thickness increased by 59.5%. Reactive hyperemia and flow mediated dilation change in brachial artery diameter increased by 11.1% and 147.7% following the program, respectively. HbA1c level changed minimally (5 to 4.9%).
Discussion: This case report suggests that RG-HIIT-FES cycling was an effective strategy to improve lean mass, and systemic vascular endothelial health in an individual with chronic SCI.

Keywords: Interval training, Functional electrical stimulation cycling, Paraplegia, Endothelial health, Body composition

Introduction

People with spinal cord injury (SCI) are more than 2 times as likely to develop cardio-metabolic related diseases (e.g., ischemic heart disease, stroke and type-II diabetes mellitus) as compared to their able-bodied counterparts.[1,2] This increased risk after SCI is thought to be largely influenced by accelerated muscle atrophy and reduced blood flow through sublesional arteries which results in impaired vascular endothelial health.[1,3–6]

An important strategy used to stimulate paralyzed skeletal muscles and improve cardio-metabolic health after SCI is through functional electrical stimulation (FES) cycling. FES cycling, has been traditionally prescribed at a moderate to high cadence (i.e., 30-50 rpm).[7,8] For instance, Griffen *et al.*[9] revealed that 10 weeks of moderate to high cadence FES cycling can increase lean mass and lower fasting blood glucose values. Interestingly, Fornusek *et al.*[10] demonstrated that mid-thigh girth change was even greater following 6 weeks of low cadence FES cycling (10 rpm). The authors attributed the increased girth to a greater level of cycling resistance permitted by the lower cycling cadence. While previous studies have been conducted on both high and low cadence FES cycling, there is an absence of investigation into the effects of FES cycling on paralyzed muscles when moderate to high cadence is combined with high resistance in an interval fashion. This is important because among able-bodied individuals, high-intensity interval training (HIIT) has been shown to decrease cardiometabolic risk in a shorter period of time than non-interval exercise programs.[11,12]

One disadvantage incurred by individuals with SCI is the decreased amount of muscle mass available for

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physical activities, and possible autonomic dysfunction which may decrease the accuracy of heart rate as a determinant of exercise intensity. Valent *et al.*[13] found that only 8 out of 18 individuals with tetraplegia demonstrated a linear relationship between heart rate and oxygen uptake. Given the difficulties inherent in monitoring HIIT cardiovascular based programs and the importance of the resistance component of exercise for restoring muscle mass in the paralyzed extremities, we developed a resistance-guided functional electrical stimulation cycling protocol that combines interval training and bouts of high resistance exercise. Healthcare professionals and those with paralytic conditions need to have evidence based information concerning the benefits of FES cycling protocols including resistance-guided HIIT-FES cycling to allow optimal rehabilitation program planning.

The purpose of this case report was to begin examining the effects of a novel HIIT-FES cycling program, using maximal resistance achieved during an incremental maximal cycling test as a means to guide intervals (RG-HIIT-FES), on cardio-metabolic health markers in people with SCI.

Case report

Participant

A 31 year old Caucasian female, 11 years post-traumatic, motor complete T10 SCI; American Spinal Injury Association impairment scale (AIS) B was recruited. At the start of the program the participant weighed 57.3 kg and was 157.5 cm in height. The participant used a manual wheelchair for locomotion and was independent in transfers. The participant had not been on a regular exercise program for at least 3 months prior to the study. All experimental measurements and procedures were approved by University ethics, and the participant provided written informed consent. Because the RT300 FES cycle is a class 2 medical device, the participant provided a signed medical prescription from her physician for FES cycling. The participant was without the following exclusionary conditions: stage 2 or greater pressure wound, joint contractures in the lower extremities, unhealed lower extremity bone fracture, uncontrolled cardiovascular disease, hypertension or diabetes mellitus, pacemaker, severe respiratory illness, severe osteoporosis (T score of -4 or less and/or a history of fragility fractures), intolerable discomfort during the cycling activity, uncontrolled autonomic dysreflexia and less than 2 years post injury.

The participant had her own RT300 FES cycle allowing home-based FES cycling. The first FES cycling session was performed in the exercise laboratory at our institution in order to verify safety and to determine baseline cycling protocol parameters. The home cycling sessions were monitored by research staff via WiFi internet connection to the individual's FES cycle in her home.

Experimental study visits

Doppler ultrasound measures

Prior to and after the 10 week program, the participant underwent the following testing: While the participant remained supine, a duplex-Doppler ultrasound unit (GE Logiq P5) was positioned for vascular endothelial function testing which included the Flow-Mediated Dilation (FMD) technique. This procedure was performed as previously reported.[6,14,15] Brachial artery measurement was selected over an artery in the lower extremity in order to demonstrate overall systemic vascular change in this closed system. The brachial artery was imaged 2–5 cm above the antecubital fossa. All vascular endothelial function data are reported in Table 1.

Muscle architecture changes of the right vastus lateralis muscle (VL) were then determined using B-mode ultrasound (GE, Logiq-P5), similar to previously

Table 1 RG-HIIT-FES Program Results for P1.

	Baseline	8 Wks. FES	Δ% 8 Wks.
Body Composition			
Body Weight (kg)	57.3	59.7	+4.2
BMI (kg/m^2)	23.1	24.1	+4.3
Body Fat (%)	33.8	34.7	+2.7
Lean Mass (kg)	36.2	37.2	+2.8
Fat Mass (kg)	18.5	19.7	+6.5
Legs Lean Mass (kg)	9.4	9.9	+5.3
Bone Mineral Density (g/cm^2)	1.07	1.06	-0.9
Resting Hemodynamics			
HR (bpm)	77	75	-2.6
SBP (mmHg)	121	129	+6.6
DBP (mmHg)	77	76	-1.3
Vascular Health			
Resting Artery Diameter (mm)	3.8	3.8	-1.3
Peak Diameter (mm)	4.1	4.4	+7.2
FMD (mm)	0.2	0.6	+144.5
FMD (%)	6.2	15.3	+147.7
Shear Stimulus (AUC)	36667	42299	+15.4
FMD normalized (AU)	0.17	0.36	+114.7
Reactive Hyperemia (AUC)	57801	64208	+11.1
Muscle Architecture			
VL Thickness (cm)	1.3	2.1	+59.5
Sub-Q Thickness (cm)	1.2	1.5	+25
Total Thickness (cm)	2.7	3.5	+30.6
Glycemic Control			
HbA1c (%)	5	4.9	-2

HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; FMD, Flow-Mediated Dilation; VL, vastus lateralis; Sub-Q, subcutaneous fat+skin; HbA1c, glycosylated hemoglobin.

published reports.[16,17] The probe was positioned longitudinally and perpendicular to the VL along the halfway point between the lateral epicondyle of femur and greater trochanter of hip (1/8th of the thigh circumference, lateral). Sub-Q thickness was defined as the distance between the skin surface and the superficial fascia of the VL. The VL muscle thickness was defined as the distance between the superficial fascia and the deep aponeurosis, and total thigh thickness was defined as the distance between the skin surface and the deep aponeurosis. This method was selected to account for changes in connective tissue rather than summing the Sub-Q and the VL thickness. All muscle architecture data are presented as an average across the 10 second recording in Table 1**.**

Blood glucose

Glycosylated hemoglobin (HbA1c) measurements, a marker of long-term glucose regulation, were obtained via an automated portable HbA1c testing device (PTS Diagnostics, A1cNow^{+}). Blood samples were obtained from a finger stick performed in the left hand. These data are presented in Table 1.

Body composition

Body composition was measured in supine by a Lunar Prodigy Advance Dual-Energy X-Ray Absorptiometry (DXA) scanner (General Electric, Madison, WI). Measurements concerning total body and regional (legs) percent body fat, fat mass, lean mass and bone mineral density were determined by the DXA Lunar software version 10.5. DXA scans prior to and after the 10 weeks of training.

Resistance-guided FES cycling maximal test

Prior to the baseline cycling test, surface electrodes were placed on the quadriceps, hamstrings and gluteal muscles as described in prior studies.[8] Electrical leads from the RT300 cycle were connected to the surface electrodes. Research staff applied electrical stimulation in an incremental manner to each muscle group to determine the amount of electricity that both produced a strong muscular contraction while remaining comfortable to the participant. This process produced the initial electrical parameters used for the insuing testing. While seated in her own wheelchair, research staff secured the FES cycle to the chair with safety hook attachments and her feet were velcro straped onto the FES cycle pedals. Vital signs were checked (heart rate, blood pressure) while at rest, and again every 5 minutes during the test and into recovery. The cycle was then started with a 2 minute passive cycling warm-up and then the electricity was ramped up to the prior determined electrical parameters. Once the muscles were activated enough to cycle the bike on their own, the motor support was turned off and the participant performed FES cycling at a cadence of 35 rpm and an intial resistance of 0.5 Nm. The resistence was increased each minute by ∼0.5–1 Nm, depending on the participants tolerance, until the legs could no longer cycle without motor assistance. At this point a cool-down phase began. This phase continued for 2 minutes to allow vital signs to return to near resting values. Blood pressure and heart rate were monitored for safety. The maximal resistance tolerated by the participant for 30 seconds was recorded as the maximal resistance performed during the test and used to calculate the high intensity intervals during the RG-HIIT-FES program, which were set at 80% of the maximum tolerated cycling resistance.

RG-HIIT-FES cycling program

Preparation for the RG-HIIT-FES cycling sessions were the same as described above for the RG-FES maximal testing, except the participant performed them at home and the results were reviewed by research staff via internet connection to the FES cycle. The participant cycled 3 times/week for 10 weeks. The cycling protocol included 30 second high intensity intervals at 80% of the highest resistance tolerated during the initial laboratory testing session. For the 30 second low intensity interval, the electrical stimulation was decreased by 50% and the resistance dropped to 0.5 Nm which was the lowest available resistance setting for the particular FES cycle. The cycling speed was maintained at 35 rpm and sessions lasted for 30 minutes. The rationale for cycling at 35 rpm stems from evidence during intial trials in our laboratory in which some individuals were so deconditioned that they were unable to successfully cycle without motor support, even at the default 0.5 Nm resistance, thus, the speed of cycling had to be low enough to allow electricity induced muscluar contractions to cycle against resistance without motor support.

Results

The participant performed 28 out of 30 possible RG-HIIT-FES cycling sessions over 10 weeks which is a 93% participation rate. The participant had partial sensation in the legs, thus, was only able to tolerate an electrical intensity of 55 mA for the quadriceps muscles, 45 mA for hamstrings, and 20 mA for gluteal muscles. Pulse width was 300 µs and frequency 40 Hz. The maximal tolerated training resistance was 1.0 Nm for the high intensity interval, 0.5 Nm for the low intensity interval. The cycling speed was 35 rpm.

Following the 10 week RG-HIIT-FES cycling program there were slight increases in body weight (57.3 kg to 59.7 kg; 4.2%), total body lean mass (36.2–37.2 kg), legs lean mass (9.4–9.9 kg: 5.3%), total body fat mass (18.5–19.7 kg: 6.4%), and body fat percentage (33.8–34.7%) (Table 1).

Resting hemodynamic values were similar (i.e., heart rate and blood pressure), while both macro- (FMD %-normalized: 0.17–0.36 AU; 114.7% increase) and micro-vascular health measures (Reactive hyperemia: 57801–64208 AUC; 11.1% increase) demonstrated signs of improvement (Table 1).

Muscle architecture also demonstrated signs of improvement for all muscle measurements, characterized by a 1.3 to 2.1 cm increase in VL (+59.5%), and a 1.2 to 3.5 cm Sub-Q increase (+25%) and total thigh thickness increase of 2.7 to 3.5 cm (+30.6%) (Table 1).

Glucose Control (HbA1c) demonstrated a minimal decrease (5 to 4.9%) (Table 1).

Discussion

There was an increase in total and legs lean mass which supports the results of Scremin *et al.,*[18] leg muscle cross sectional area increased from 22% (adductor magnus and hamstrings) to 31% (vastus medialis-intermedius) in 13 individuals with chronic SCI after 52 weeks of high cadence FES cycling. This is important because individuals with acute SCI have been reported to have only 60–65% of the lean mass of their able-bodied counterparts and those with chronic motor complete SCI typically have reductions of 45–80% in skeletal muscle cross sectional area in paralyzed limbs.[19–21] Both reduced muscle mass and increased fat mass are considered risk factors for cardiometabolic diseases.[22] Body weight and fat mass did increase which may in part be explained by a lack of nutrition counseling or monitoring of caloric intake in the study.

Concerning vascular health, there was an increase in FMD% and reactive hyperemia. These improvements in peripheral vascular health are in agreement with Zbogar *et al.*[23] who demonstrated a 63% increase is small artery compliance of the radial artery in four women with chronic SCI after high cadence FES cycling 3 times per week for two separate training phases (16 weeks passive cycling and 12 weeks with gradually increased resistance during FES cycling). Finally, HbA1c percentage levels changed minimally (5.0–4.9), however; both scores were in a normal range.

Limitations

A case study of one limits the ability to demonstrate a casual inference. A secondary limitation was that the participant was unmonitored with respect to food intake and dietary guidelines were not provided.

Conclusion

This study indicates that RG-HIIT-FES cycling 3 times per week for 10 weeks without dietary monitoring can increase total body and legs lean mass and improve cardiovascular health markers which are all encouraging signs for this newly developed protocol. However, a larger randomized controlled study is required to establish the effectiveness of this modified FES cycling protocol.

Disclaimer statements

Contributors None.

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Conflict of interest The authors report no conflicts of interest.

Ethics approval This study followed the principles of the Declaration of Helsinki.

Disclosures None.

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